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Salinity fluctuations in mangrove forest of Gazi bay, Kenya: lessons for future research

Elisabeth Robert[1,2,], Nele Schmitz[1,2,*], Hamisi Ali Kirauni[3] and Nico Koedam[1]*

Summary

Studies on mangrove ecosystems that deal with the interaction of organisms and their environment very often draw conclusions based on only a restricted number of soil water salinity measurements. As inundation by salty water is the most typical characteristic of the mangrove environment, the authors addressed the temporal and spatial fluctuation of soil water salinity at seven locations in the mangrove forest of Gazi Bay, Kenya. As a pilot study, the research team measured soil water salinity twice a month, at neap tide and at spring tide, during one year. It can be concluded that the soil water salinity in mangrove forests can be highly variable in time as well as in space and depends on a complex interaction between inundation frequency, canopy closure, fresh water input and soil texture. Mangrove researchers should therefore pay attention to the differences in local site conditions inside the mangrove forest and conduct salinity measurements that cover the temporal and spatial fluctuations before drawing conclusions on the relationship to this environmental condition.

Introduction

As mangrove ecosystems are ecologically and economically of high importance but fast disappearing and degrading (Duke*, et al.*, 2007), it is important to conduct scientific studies - fundamental as well as management based – to obtain the necessary knowledge to preserve, to protect and to restore mangrove forests. Ideally, such studies should not only deal with the organisms of the mangrove ecosystem – fauna as well as flora - but also with the interaction between these organisms and their environment. The most characteristic elements of the mangrove environment are a frequent inundation and saline water (Tomlinson, 1994), both not only strongly determining the life of the mangrove inhabitants (e.g. Fratini*, et al.*, 2004, Schmitz, 2008, Robert*, et al.*, 2009) but also, by selection, nature's diversity and assemblage composition.

Studies dealing with the relationship between organisms and their environment often generate conclusions from a restricted dataset – spatially and/or temporally – of environmental parameters. The purpose of this research is to study the variability of the soil water salinity on a spatial as well as on a temporal scale in the mangrove forest of Gazi Bay, Kenya, a well studied site as concerns mangrove research. The results of the study are intended to evaluate the fluctuation of one of the key parameters of the mangrove environment on an intra-annual scale and this for different study sites situated relatively close to each other.

[1] Laboratory of Plant Biology and Nature Management (APNA), Vrije Universiteit Brussel (VUB), Pleinlaan 2, B-1050 Brussels, Belgium, Tel.: +32 2 629 34 14, Fax: +32 2 629 34 13. E-mail: erobert@vub.ac.be (E.M.R.R. – PhD student); nschmitz@vub.ac.be (N.S. – postdoctoral researcher); nikoedam@vub.ac.be (N.K. – professor)
[2] Laboratory for Wood Biology and Xylarium, Royal Museum for Central Africa (RMCA), Leuvensesteenweg 13, B-3080 Tervuren, Belgium, Tel.: +32 2 769 56 13.
[3] Kenya Marine and Fisheries Research Institute (KMFRI), PO Box 81651, Mombasa, Kenya, Tel.: +254 414 75 15 14. E-mail: hamisikirauni@yahoo.com (H.A.K. – scientific employee)
[*] The first two authors have equal contribution on this work.

Study area

Study sites

The study area is situated in Kenya, in the mangrove forest of Gazi Bay (39°30'E, 4°25'S), which covers about 600 ha (UNEP, 2001, Neukermans, *et al.*, 2008) and is situated approximately 50 km south of Mombasa. The mangrove forest has a tidal amplitude of about 3.8 m with a maximum of 4.1 m (Kenya Ports Authority tide tables for Kilindini, Mombasa) and is characterized by a sloping topography (Matthijs, *et al.*, 1999). Seven sites spread over the mangrove forest (Figure 1) were studied with as common characteristic the occurrence of the mangrove tree species *Avicennia marina*.

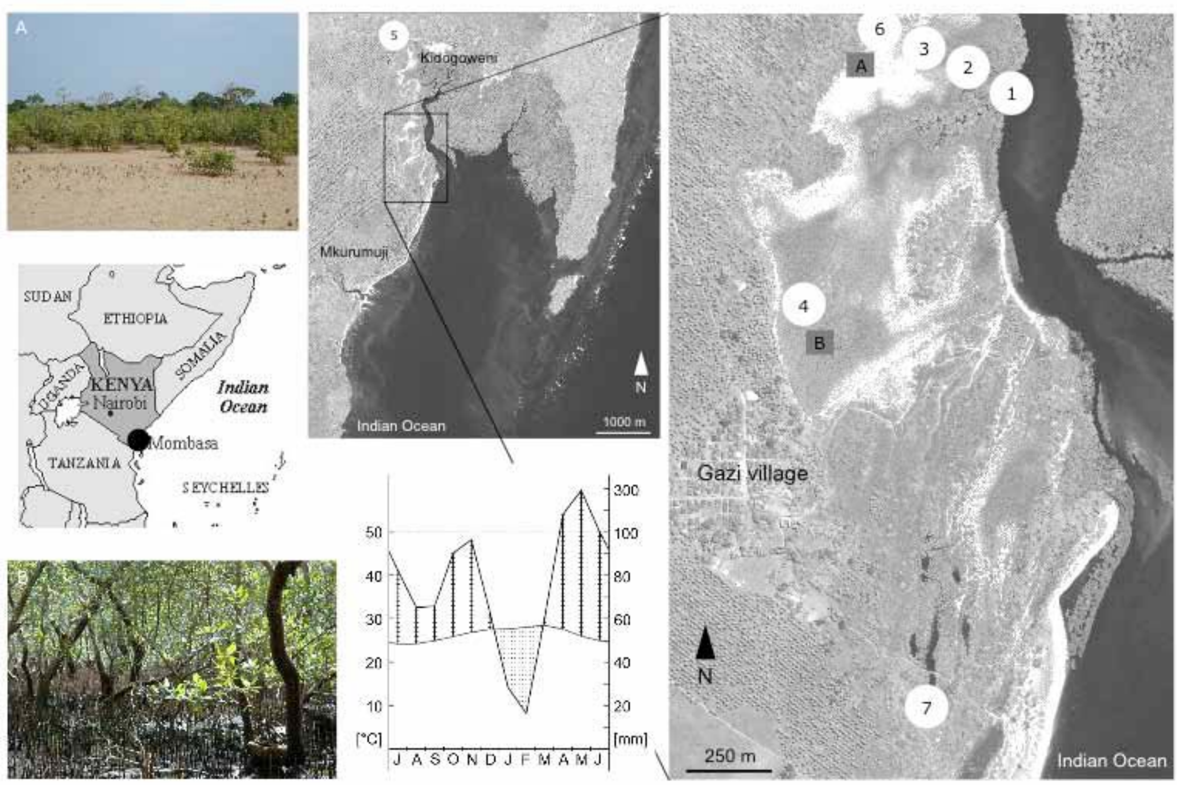

Figure 1: Description of the study area. Map of east Africa (left middle) *showing the location of Gazi Bay on the Kenyan east coast (black dot) and two QuickBird satellite images of Gazi Bay (Kenya) (middle up and right), acquired in 2002 (Neukermans, et al., 2008) situating the seven study sites in the mangrove forest of Gazi Bay and the location the pictures A and B (left up and left down) have been taken. The two seasonal rivers that provide freshwater to the mangrove forest are indicated on the satellite image in the middle. Climate diagram (middle down) of Mombasa (adapted from Lieth, et al., 1999) representing the climate of the African east coast. Temperature (°C) is shown on the left and precipitation (mm) on the right vertical axe. Precipitation scale is reduced to 1/10 above the horizontal line. Pictures: Nele Schmitz and Elisabeth Robert.*

Climate description

The climate along the Kenyan coast is characterized by a bimodal distribution of the precipitation (Figure 1). A distinct dry season (January - February) is followed by a long (April - July) and a short (October - November) rainy season (Figure 1). During the wet season, the rivers Mkurumuji and Kidogoweni (Figure 1) provide an important freshwater source for the mangroves of Gazi Bay. The average temperature at the Kenyan coast ranges from 22 to 30°C, with a mean relative humidity of 65% to 81% (annual averages of minimal and maximal values for Mombasa for the period 1972 - 2001, data from the Kenyan Meteorological Department, Mombasa, Kenya).

Material and methods

Environmental data collection

For each of the seven sites (i) soil texture was determined by standard field characterization methods (GLOBE, 2005) and (ii) height above sea level and inundation frequency were calculated based on the Kilindini Harbour tide tables (Kenya, 39°39'E, 4°04'S). The local flooding level was measured with tracing paper impregnated with ecoline dye. For study site seven the exact height above datum and inundation frequency could not be determined. Here, the mangrove trees grow in a basin and are disconnected from the rest of the basin type forest by a raised road. Consequently, the inundation frequency differs in rainy and dry season since the water level reaches more frequently the height of the road during the former.

From April 2007 to February 2008, the salinity was measured at each site with a hand-held refractometer (ATAGO, Tokyo, Japan / 0 – 100 ‰). Here for, soil water was sampled two times a month, once during neap tide and once during spring tide, at approximately 25 cm depth and at three positions scattered over each of the seven study sites. This was done with a punctured plastic tube connected to a vacuum pump or by digging a hole of the same depth when fine soil particles clogged the filtering tissue wrapped around the punctured plastic tube. Soil water salinity has only been measured at 25 cm depth so that the variation in soil water salinity with depth is not within the scope of this study.

Data analysis

To show the variation in soil water salinity, median, minimum and maximum values were calculated. However, at three of the seven sites no soil water could be extracted at certain dates (Figure 2, black stars). In these cases, the highest soil water salinity measured during fieldwork expeditions in the rainy season of 2005 and 2006 and the dry season of 2007 and 2009 was taken. For the basin forest the highest salinity of the water in the puddle was taken. Monthly rainfall data were averaged for the period 1966-2006 and are from the Kenyan Meteorological Department, Mombasa, Kenya.

Results

The seven study sites, although situated in one mangrove forest, differed seriously in environmental conditions (soil texture – height above sea level – inundation frequency) (Table 1). The annual average salinity as well as the pattern of variation of the soil water salinity over the year was different in different study sites (Figure 2).

Discussion

The study could not indicate one factor as being the main environmental characteristic determining soil water salinity. Instead, different environmental factors contribute to the annual average salinity as well as to the pattern of variation of the soil water salinity over the year. But although no clear-cut relationships between soil water salinity and environmental characteristics could be deducted from Figure 2, some trends were observed.

Table 1. Environmental description of the seven study sites in the mangrove forest of Gazi Bay, Kenya.

Location	Soil Texture	H_{asl} (m) †	Inundation frequency ‡ (days/month)
site 1	silty clay	2.18	30
site 2	sandy loam	2.84	23
site 3	loamy sand	3.25	14
site 4	clay loam	3.35	12
site 5	clay loam – loamy sand	3.49	8
site 6	sandy loam – loamy sand	3.63	5
site 7	loamy sand – sandy loam	3.66-3.80*	5-3*

† Height above sea level.
‡ Inundation frequency based on the Kilindini Harbour tide tables of 2009.
* See 'Material and methods – Environmental data collection' for more information.

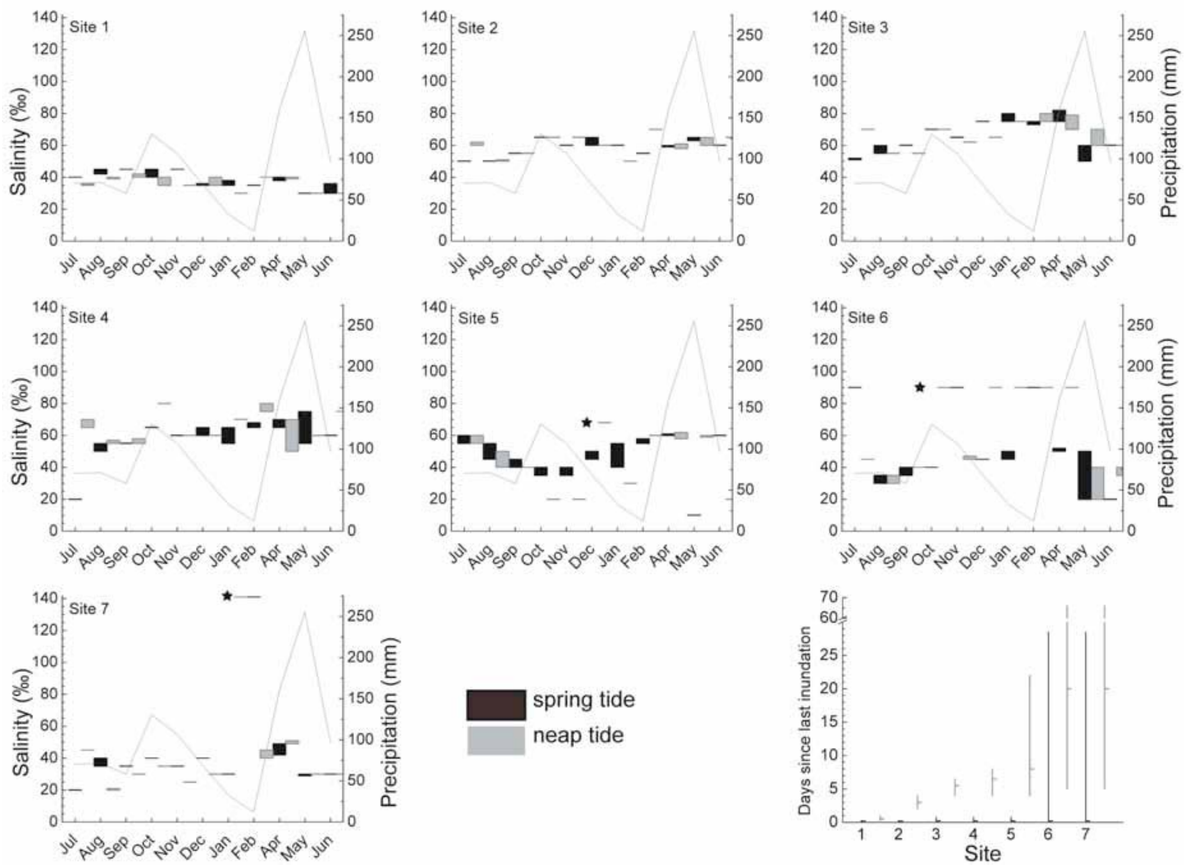

Figure 2: Spatial and temporal variation in soil water salinity in the mangrove forest of Gazi Bay, Kenya. *Bars represent the salinity range of three measurements on the day when the high tide was highest during spring tide or lowest during neap tide. Black stars indicate moments when no soil water could be extracted and the highest soil water salinity measured in the period 2005-2009 was plotted (see also 'Material and methods – Data analysis'). The number of days since the last inundation on the day of measurement was plotted for each site as a monthly average (min-median-max).*

First, study sites that are daily inundated have a rather constant soil water salinity compared to study sites that are inundated only a few days a month (Figure 2, site 4-7 *vs.* 1-3). Non-frequent inundation implies longer dry periods during which the soil water evaporates leading to an increase in soil water salinity as alternating with periods of dilution by rainwater and salinity decrease. In contrast, frequent inundation permanently saturates the soil with water of seawater salt content. A similar effect was expected from the monthly tidal rhythm. At neap tide, study sites experience a drought period for one day up to more than two months (Figure 2). At spring tide, all sites are flooded at least once a day except for the most landward site and the site that is disconnected from the sea by a road (Figure 1 and 2, site 6-7) which experience drought periods of maximum one month. However, no link was found between tidal period and soil water salinity.

Second, the annual average salinity increased with decreasing inundation frequency in the seaward study sites (Figure 1 and 2, site 1-3). Further landward this trend broke down for the annual average but not for the maximum salinity, with study site 5 as an exception. In general, the disrupted trend with inundation frequency in site 4 to 7 could be related to changes in fresh water influence, canopy closure and soil texture. While site 3 is an open forest (Leaf Area Index of 0.23) with small trees (mean tree height: 2m) (Schmitz*, et al.*, 2008), the mangrove forest at study site 4 has comparably a closed canopy (Leaf Area Index of 1.18) (Schmitz*, et al.*, 2008) and a muddy soil (Table 1), both counteracting evaporation and thus also counteracting increase of soil water salinity. In study sites 5 and 6 fresh water input affects the soil water salinity. Site 5 is situated upstream the Kidogoweni river causing soil water salinity to match the precipitation curve. Site 6 is located at the border of the mangrove forest experiencing high amounts of freshwater run-off during the rainy season, leaching the sandy soil (Table 1). Due to the sandy soil in combination with an open canopy (Leaf Area Index of 0.62) (Schmitz*, et al.*, 2008), it is also study site 6 in which drought has the biggest impact. In study site 7 the main factor determining soil water salinity is the topography, which is like a basin. Seawater is thus standing and the salinity in the puddle gradually increased from the surface to the bottom. Stratification of the puddle water can thus explain why evaporation or fresh water input did not directly affect soil water salinity. Only in the middle of the dry season - around February - values up to 140 ‰ were measured in the last bit of water before the basin dried out completely.

Soil water salinity has a direct effect on the water relations in trees as high and fluctuating soil water salinity makes high demands on the water transport system by creating high risk of air blocking the water transporting canals (Cochard, 2006, Naidoo, 2006). This is especially true for mangrove trees inundated by saline water regularly to twice a day. Spatial differences in soil water salinity influence the species distribution of the mangrove forest due to differences in the ability to support high and fluctuating salinity between mangrove trees (Verheyden *et al.*, 2005, Schmitz, 2008, Robert *et al.*, 2009). Tree species distribution on its turn influences *e.g.* seedling dispersal (different root complexes act differently in propagule dispersal and establishment – Di Nitto *et al.*, 2008) and mangrove fauna (*e.g.* Smith, 1987), so that we can conclude that salinity is one of the major factors influencing and structuring life in the mangrove ecosystem.

Conclusion

The variability of the mangrove forest in terms of soil water salinity as observed in the mangrove forest of Gazi bay (Kenya) should alert all those involved in mangrove studies. The factors contributing to this dynamism in time as well as in space, their interactions and the magnitude of the resulting fluctuations will vary between mangrove forests all over the world. Nevertheless, the message learnt from this study is of general importance. Soil water salinity cannot be predicted from inundation frequency alone and the additional influencing factors such as canopy closure, topography, fresh water input and soil texture can vary significantly within only a few hundred meters. The great number of micro-environments a mangrove forest can consist of should be taken into account to get better understanding of the functioning of the mangrove ecosystem and to be able to make high-impact conclusions that go beyond specific mangrove sites.

Recommendations

Soil water salinity, inundation frequency and soil texture can be determined with cheap and fast methods. The authors recommend that it should be standard practice for mangrove researchers to carefully compare different locations of a mangrove forest for these environmental parameters given their importance to obtaining a reliable reflection of the variation in soil water salinity. Moreover adequate number of measurements has to be carried out to cover the local variation not only in space but also in time. In the event that this is not possible, the limitations of the soil water sampling strategy should be reported and considered when drawing conclusions.

Acknowledgements

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Development of Mangrove paddy fields in Casamance Southern Senegal

Boubacar Barry[1]

Summary

Mangroves areas in Casamance have been traditionally used for rice growing, fishing, fish culture, shell picking and wood. Senegal has been affected by drought since 1963 and this has had an adverse effect on the mangroves leading to a decrease in the total area. Intensification of agriculture and increasing population pressure has resulted in increased erosion and siltation. Given the shortage of rainfall due to recurrent droughts over the last three decades, one can easily observe a tendency towards increased salinity of soils and the underlying water table. Site development has become the only solution to the salt intrusion problem since early 1970s.The present paper focuses on the different types of site development such as the traditional polder and anti-small dams and their role in increasing rice production.

Background

The West African country of Senegal (Figure 1) is primarily an agricultural country. Agriculture accounts for about 28% of the GNP and provide employment for 80% of the economically active population.

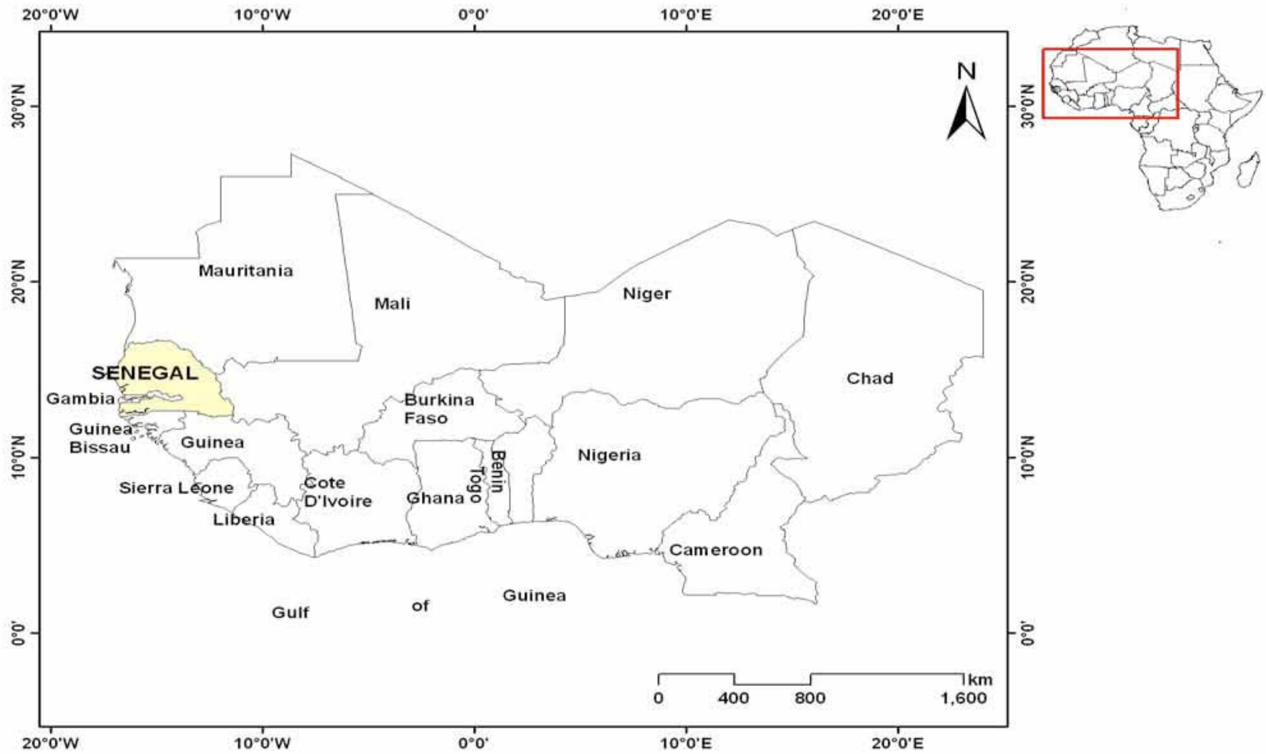

Figure 1: Map of Africa and West Africa showing Senegal

[1] *Boubacar Barry. International Water Management Institute (IWMI) Regional Office for Africa and Sub Regional Office for West Africa C/o CSIR Campus, Martin Odei Block, Airport Res. Area, Accra, Ghana.*

PMB CT 112,Cantonments, Accra, Ghana. Telephone: +233-(0) 21 784753-4 Fax: +233-(0) 21 784752

Email: iwmi-ghana@cgiar.org

In recent years, cereal production especially rice has not been sufficient to meet growing needs. Currently there is a deficit of about 200 000 tons of cereal grains each year. During the late sixties and early seventies, due to rapid growth of urban areas as a result of population migration especially the young from rural to urban areas, the failure_of food production caused by policies favoring cash crops, the instability of world prices, and the frequent Sahelian droughts, the country became painfully aware of its dependence on imported food, notably rice. Since 1977, due to generalized drought, Senegal has imported more than 600,000 tons of cereals every year. At present time, domestic rice production covers only 15 to 30 % of the country's annual needs.

Because of economic instability arising from the combined factors of heavy dependence on imported food largely due to unstable rainfall patterns, agricultural development in the mangrove area in Casamance has become a main priority along with irrigation and full water control for agricultural production along the major rivers. An ambitious programme of soil and water management was developed during the early 1980's in the mangrove area of Casamance to improve food production.

For many years, the Casamance region was a food self-sufficient region. In recent decades, this region has experienced food deficits. In the Casamance region the annual rainfall has decreased from 1 500 mm to less than 1 000 m. Most strikingly, during the period from 1966 to 1980, there was a more than 20% reduction in annual rainfall, and over the period 1980-1990 the average was even lower.

Characteristics of Mangrove Areas in Casamance

The mangrove area of Casamance in the South-West of Senegal consists of intra-tidal flats with riverain mangrove forest and 'tannes', *i.e.* saline marshes partly containing bare surfaces. The soils are acid sulphate soils, very shallowly developed on peaty sulphidic mud clays and sands, and subject to tidal flooding. The mangrove area is concentrated in the estuary of the Casamance River. Since the mangrove area in Casamance is only marginally suited for rice cultivation, a reduction of 20 to 30% in rainfall has been disastrous for paddy yields. With insufficient rainfall, there is inadequate leaching of the polders and as the salt level increases the production of rice becomes nearly impossible.

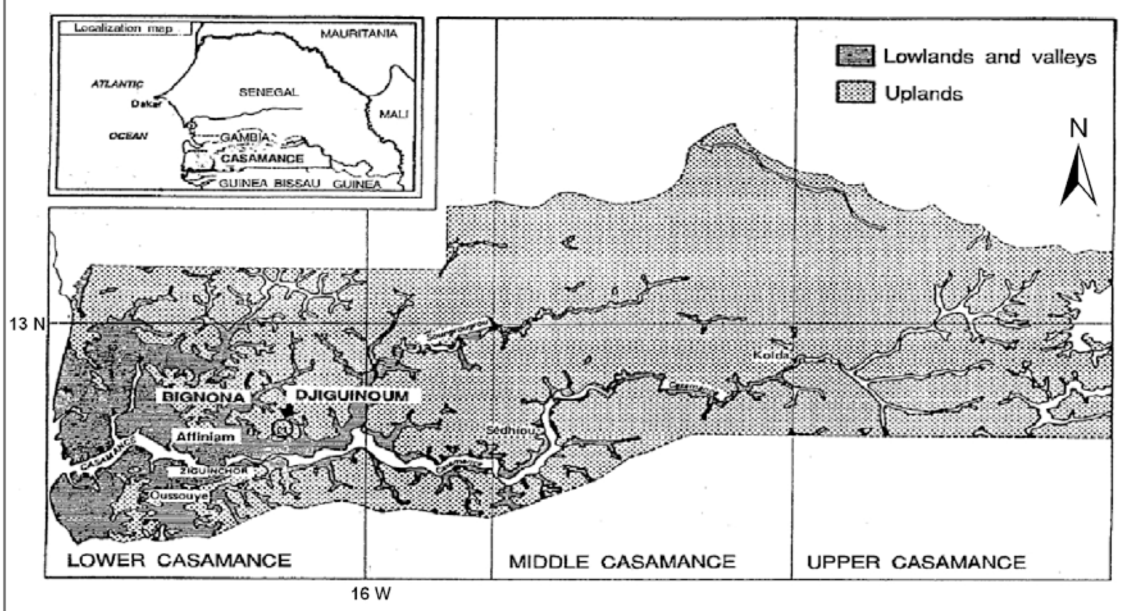

Figure 2: Map of the Casamance Region of Senegal

Geographically, the saline proportion of the Casamance River estuary extends 220 km into the country; salt water regularly rises as far as 130 km inland. Salt content reaches its maximum level in June and its minimum level in October. The salinity at the town of Ziguinchor varies between 19 and 37 grams of salt per liter. The maximum amplitude of the tide is approximately one meter, and all of them are subject to the seawater infiltration,. Since the region is quite flat, all of the backwaters (marigots and bolons) are also affected by salt over much of their length.

Another result at the level landscape is a lack of runoff. On average, only 6% of the rainfall in the Lower Casamance goes into runoff, thereby helping leach mangrove rice fields. Given the shortage of rainfall during the 1970s, 1980s and late 1990s, the increasing accumulation of salt in the soil, combined with conflicts and political turmoil has led to the declined of mangrove rice production. Thus the number of abandoned mangrove rice fields has increased over the last two decades all over the Casamance Region. Along the tidal portions of the river basins, there is a tendency not only towards increasing salinity of the river beds themselves, but also toward increase of the underlying water table. This salinization process occurs at the end of the rainy season as a result of high tides which feed the water table. Consequently, not only the polders, but also the rice fields located on the first level of terraces, are negatively affected by the shortage of rainfall and the problem of salinization. In the mangrove areas the continental bedrock, mainly sandstone, is found under unconsolidated mud clays and sands, and has a depth of up to 20 meters. The chemical composition of the mud varies little along the estuary. The mud is relatively poor in Ca, K and trace elements.

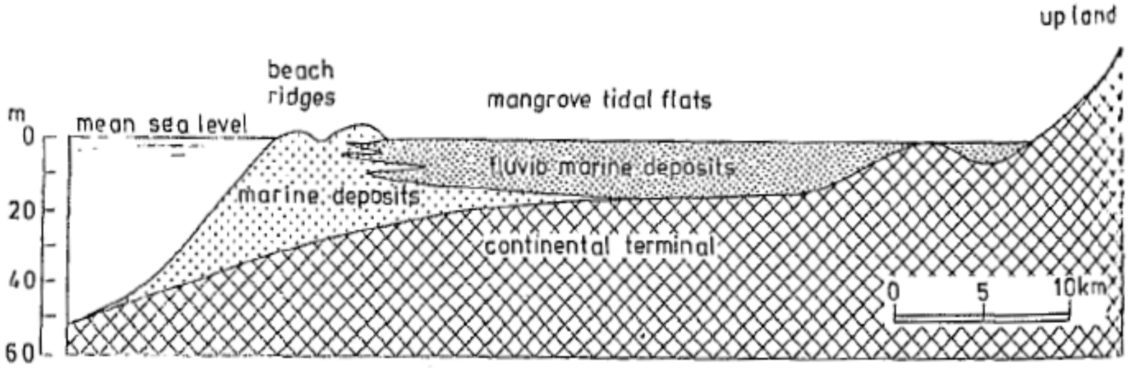

Figure 3: Typical relations between continental terminal and marine and fluvio-marine soil deposits of the mangrove area

Agricultural Development of Mangrove Areas in Casamance
Mangrove rice cultivation has been practiced in the Casamance region by farmers for centuries. The traditional Diola system for reclaiming mangroves is based on the judicious use of the movements of the tide. In the absence of free water, farmers managed earlier to leach the salt from their fields without lowering the pH. This was done by allowing a continued re-admission of salt water during the dry season. In years with abundant rainfall, fields could produce as much as 3 tons of paddy rice per hectare with no fertilizer and, in many cases, no weeding. The double dyke systems, which makes it possible to tap all the resources of the mangrove (wood, charcoal, fish, pasture, rice farming), has been widely adapted but requires a great deal of labor. Given the high frequency of years with low annual rainfall and the flight of young people toward the cities, the future of mangrove rice cultivation is now in question.

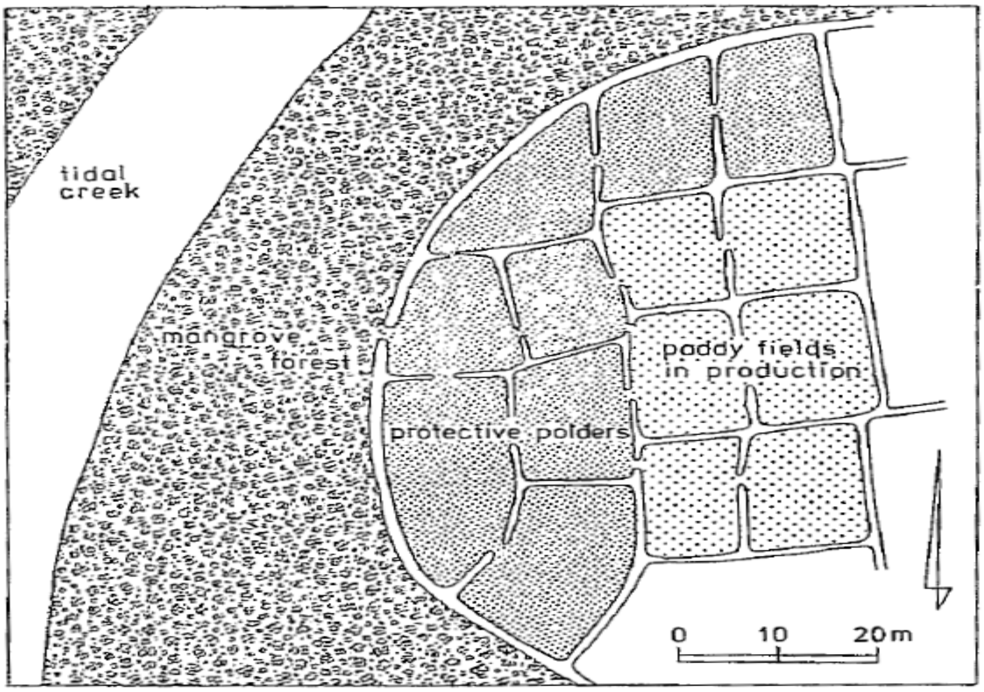

Figure 4: Traditional site development

Site development (polders, drains, anti-salt dams) in Casamance focuses on the removal of the salt by means of fresh water retention and partial exclusion of brackish water. The difficulty encountered in these systems includes finding a reasonable balance between the exclusion of saline water and the drying out of the soil which may provoke a drastic decline of pH.

The low level of rainfall in recent years has dramatically reduced the amount of fresh water available for leaching the salt out of these fields, and thus diminished the possibility of site development. Research results from different sites (Madina, Tobor, Djibelor and Guidel) show that site development helps convert the surface horizons from acid sulfate soil to a para-acid sulfate soil and, with more fresh water (greater rainfall levels, fresh water retention dykes), the polders could again become viable for rice production (Beye,1977, Marius, 1980 and Barry, 1991). That is why the Government of Senegal launched, in 1994, an important soil and water programme in Casamance, aimed to improve rice production in the region. The construction of small anti-salt dams in most of the valleys remains the primary objective.

It is estimated that a total of 100 000 hectares of mangrove land could be developed for agriculture in Casamance. Most of this potential lies in the Lower Casamance region, along the main tributaries of the Casamance River. These programmes are less ambitious than the national programmes of Soil and Water Conservation (SWC), which are designed for large watersheds of several hundreds of square kilometers, and involve sophisticated water control systems. The small anti-salt dams are directed toward small watersheds, not larger than several hundreds of hectares, and are built and managed by smallholder farmers of one or, at the very most, a group three villages. Most of the fields protect by the anti-salt dam are not strongly affected by the salt and the main problem encountered is to keep a sufficient depth of fresh water in the plots during the whole growing season.

The anti-salt dam consists of a dyke and one or two reinforced concrete structures. The dykes are 400 to 1 000 meters long, 4 to 6 meters wide at the bottom, and 2 to 4 meters wide on the top. Their height varies between 1.5 to 2.5 meters. In many cases, the dyke is built by farmers who share the land upstream and downstream of the dam. In general, a road which crosses the valley is used as a foundation bed. This also presents the advantage of facilitating the access to many villages during the rainy season, mainly during the floods.

A reinforced concrete structure located in the affluent bed consists of two or four gates (1.5 m wide); each gate is designed to have a rectangular weir of 20 centimeters high and 60 centimeters wide at the bottom. In order to retain water behind the dam, farmers must close the gates by installing two lines of planks on the weir, and fill the spaces in between them with mud. The planks are placed one on top of the other. The number of planks depends on the farming calendar. Each plank is 20 cm in height and is slightly longer than the gate width. At the beginning of the rainy season, farmers use two planks to retain a certain amount of water to flood the lowest paddy field and to dissolve the salt. Water will then be flushed out by removing the planks. This type of operation has to be done as many times as needed to get good conditions for growing rice, in many cases, repeatedly until mid-July, when farmers start plowing their plots. After the rice transplanting operation, which begins mid-August, farmers use more planks to retain additional water as the rainy season ends. Only after big storms is excess water released to avoid flooding the plants. During the dry season, the gates remain closed; sea water is not admitted.

In accordance with the location of their plots on the topo-sequence, farmers decide whether or not to release a part of the water behind the dam. Often there is no agreement among landowners, or a final decision is made too late. Sometimes the problem of how much water to release from the reservoir can be more complicated, as in when paddy fields downstream from the dams do not get enough water to leach the salt out.

Today, more than 100 dams have been built in Casamance in order to protect mangrove paddy fields against sea water intrusion during the high tides of the dry season and to store fresh water during the rainy season. It is estimated that more than one third of the mangrove paddy fields were earlier abandoned in Casamance because of the high salinity of the water table. The fresh water stored behind the small ant-salt dam has helped over the years leach the salt out the mangrove paddy fields and has facilitated rice growth after reclamation of the abandoned paddy fields. In most of the valleys where small anti-salt dams have been built, rice production has substantially increased. Perhaps the best example of this increase is the Katoure valley located 10 km south east of Ziguinchor, where for more than one decade, the mangrove paddy fields affected the salt water intrusion were simply abandoned. Only two years after the construction of the dam, however, the average rice paddy yield in those same fields was 3.5 tons per hectare.

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Variability in the abundance & recruitment of *Fenneropenaeus indicus* and *Metapenaeus monoceros* postlarvae and juveniles in the Ambaro bay mangroves of Madagascar

Marguerite Voahirana Rasolofo[1] and O. Ramilijaona[2]

Summary

*The Malagasy shrimp sector is currently focusing on shrimp farming in view of a drastic reduction in fisheries production. To better understand the recruitment of penaeid shrimps in maritime fisheries, research was conducted on Fenneropenaeus indicus and Metapenaeus monoceros species in two rivers at the Ambaro Bay: the Ambohinangy and the Ambazoana Rivers. The variations in abundance of size categories (postlarvae, small juveniles and large juveniles) and the migration of shrimps were sampled from September 2004 to August 2005 with a net known as "**sihitra**" used in traditional fishing. The influence of environmental factors (rain, salinity and temperature) on the recruitment is analyzed. A cross section of 4,198 individuals (58% F. indicus, 42% M. monoceros) were sampled and the predominance of small juveniles confirms the nursery role of the area under study. The seasonal development of size categories in the sample is almost similar for the two species with a pronounced abundance of postlarvae at the beginning of the wet season and the dry season; while the large juveniles are more abundant at the beginning and during the wet season. A strong rainfall intensity inhibits the immigration of F. indicus postlarvae and the temperature of mangrove waters promotes the emigration of large M. monoceros juveniles. The research examines the effects of climatic factors and the impacts of shrimp farming on mangroves, with some recommendations for the development of a sustainable shrimp resources management.*

Introduction

In Madagascar, mangroves cover a surface area of 303,814 ha (FAO, 2007). These ecosystems are high productivity areas for the coastal aquatic environment and provide preferred habitats for juveniles of animal species looking for shelter (Robertson & Duke, 1987, Sasekumar *et al*., 1992). Animals residing in the intertidal area play a significant role in the production of detritus and trophic flow in mangroves. Detritus are the primary food for penaeid shrimps and through the food chain are closely linked to the productivity of these areas. Mangroves used by shrimps as habitat during the juvenile phase of their biological cycle are called nursery areas[3].

In Madagascar, shrimp fisheries occupy a predominant position in the national economy with a turnover of € 68 million for industrial fishing in 2002 (Rajaosafara, 2006). For some years, shrimp fishing has drastically reduced in terms of profitability and currently, the Malagasy shrimp sector is oriented towards aquaculture to meet the ever-growing

[1] Researcher at the Department of Aquatic and Coastal Ecosystems, National Centre for Environmental Research, B.P. 1739, Fiadanana, Antananarivo 101, Madagascar, Mobile : 261330463625, E-mail : mrasolovoa@yahoo.fr

[2] Professor at the Department of Animal Biology, Science Faculty, University of Antananarivo, BP 906, Antananarivo 101, Madagascar,-Mobile : 261-331 287 749, Email: oramilijaona@yahoo.fr

[3] Nursery: Area in which the juveniles of a species gather to feed themselves.

global demand for seafood. However, it should be noted that the ecological impacts of aquaculture activities on mangrove ecosystems are tremendous: deforestation of mangroves, modification of water quality in environments receiving the wastes, salinization phenomenon, and reconversion of tannes causing a loss of habitats, particularly for the avifauna. These mangrove and coastal aquaculture-related problems generally originate with aquaculture management practices and with the poor enforcement of environmental regulations. In the area of shrimp captures, the reasons for fluctuations may be linked to environmental factors. These have an impact on the survival or mortality at younger stages (larvae and postlarvae) thus influencing the recruitment of shrimps in maritime fisheries.

Our study on the dynamics of young shrimps in mangrove areas is conducted following the hypothesis that interannual and seasonal variations of the recruitment at sea of penaeid shrimps depend on the availability of young shrimps in nursery areas under the influence of environmental conditions. The aim of the study is to determine the abundance, distribution and movement of young shrimps in estuaries. The survey was conducted through experimental observations on the basis of *Fenneropenaeus indicus* and *Metapenaeus monoceros* samplings, the most common species in fishery captures. As one of the main fishery zones of the West coast of Madagascar, the Ambaro Bay was selected as the study site.

Equipment and methods

Study area

The Ambaro Bay is located on the North-west coast of Madagascar between longitudes 48°30’ and 48°53’ East and latitudes 13°15’ and 13°30’ South (Figure 1). The bay is lined with mangroves along the intertidal zone over a few kilometers upstream from the estuaries. The zone under study experiences a sub-humid tropical climate characterized by a dry and cool season, from the beginning of May to the end of October, and a rainy and hot season, from early November to the end of April. As for the entire Western part of the coastal area, the tide at Ambaro Bay is semidiurnal and regular. The tidal range varies from 3 to 3.5m.

Sampling

Samplings were done from September 2004 to August 2005 in the two estuaries of the Ambohinangy and Ambazoana Rivers located in the southern part of the bay (Figure 1). Three sampling stations were established along the rivers; Station 1 is located at the opening of the river; Station 2 and Station 3 were established at 1km and 3km upstream from Station 1 respectively. In each station, temperature and salinity measurements have been carried out at a depth of less than 0.50m under the surface of the water. Rainfall data are provided by the weather station of the Nosy-Be airport located 30km to the west of the zone under study.

Samplings were taken every fortnight during spring tides. The biological material was sampled using a rectangular pocket-shape net named **sihitra** with an aperture size of 1.0 to 2.0mm. The net has the advantage of being usable within mangrove areas. It is pulled against the current by two men; the lower edge is maintained just above the water level.

The sampling takes place one to three hours before the low tide, following a one-minute haul. Penaeid shrimps are sorted from vegetable debris and other organisms.

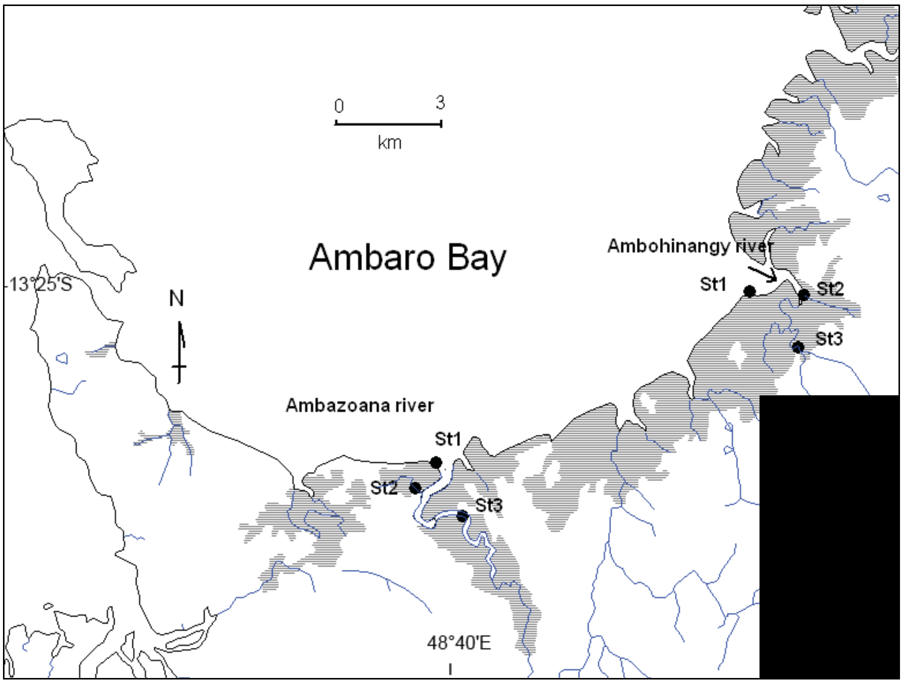

Figure 1: Location of sampling stations at the Ambaro Bay. Hachured sections represent mangrove ecosystems (St1: Station 1; St2: Station 2; St3: Station 3)

At the laboratory, each specimen was identified according to Motoh & Buri (1980) and the cephalothoracic length (CL)[4] of shrimps was measured using binocular magnifying glasses for shrimps with a CL<3mm and a caliper was used for the largest ones. The shrimps were grouped in 3 size categories: *postlarvae* (CL<3mm) *small juveniles* (3mm<CL<7mm) and *large juveniles* (CL>7mm).

Data processing

The abundance is expressed by the density (n.m^{-2}) which is the number of shrimps captured by m^{2} on a surface swept by the device. Immigration in mangrove areas was estimated according to the percentage of postlarvae abundance. Emigration was examined based on the percentage of large juveniles density. The correlation between the environmental parameters and migration indexes is translated by the Pearson's coefficient.

Results

Specific composition and numbers of samplings

Among samplings, the most numerous penaeid shrimps were the *Metapenaeus stebbingï*, *Fenneropenaeus indicus*, *Metapenaeus monoceros*, while *Penaeus semisulcatus* and *Penaeus japonicas* were less numerous. A cross section of 4,198 individuals (58% *F.*

[4] LC : Cephalothoracic length is measured between the orbital cavity and the back edge of the shell.

indicus, 42% *M. monoceros)* were captured during the sampling period. The CL size of young shrimps is between 0.8mm and 22.0mm.

Abundance

The average density of *M. monoceros* (0.37 $\pm$ 0.23 shrimps.m^{-2}) irrespective of categories, has a low representation as compared to *F. indicus* (0.60 $\pm$ 0.133 shrimps.m^{-2}). The category of small juveniles dominates in abundance as compared to the total number of young shrimps. Moreover, the large juveniles are more numerous as compared to postlarvae.

a) Spatial variation

Between the two rivers, the analysis of the average density variations for the different size categories did not show any significant difference between the two species (P = 0.599 for *F. indicus* and P = 0.933 for *M. monoceros*). However, in the stations, the abundance distribution showed differences among *F. indicus* ($0.01<P<0.05$).

b) Seasonal variations

The seasonal development of abundance is almost similar for the two species. Postlarvae are abundant at the beginning of the wet season (October-November), at the beginning of the dry season (March to May) and during the dry season (July to August). Small juveniles are constantly available year round and the large juveniles follow almost the same monthly development as the small ones. Growth periods are displayed by a simultaneous increase of size categories and are observed at the beginning of the wet season (Figure 2).

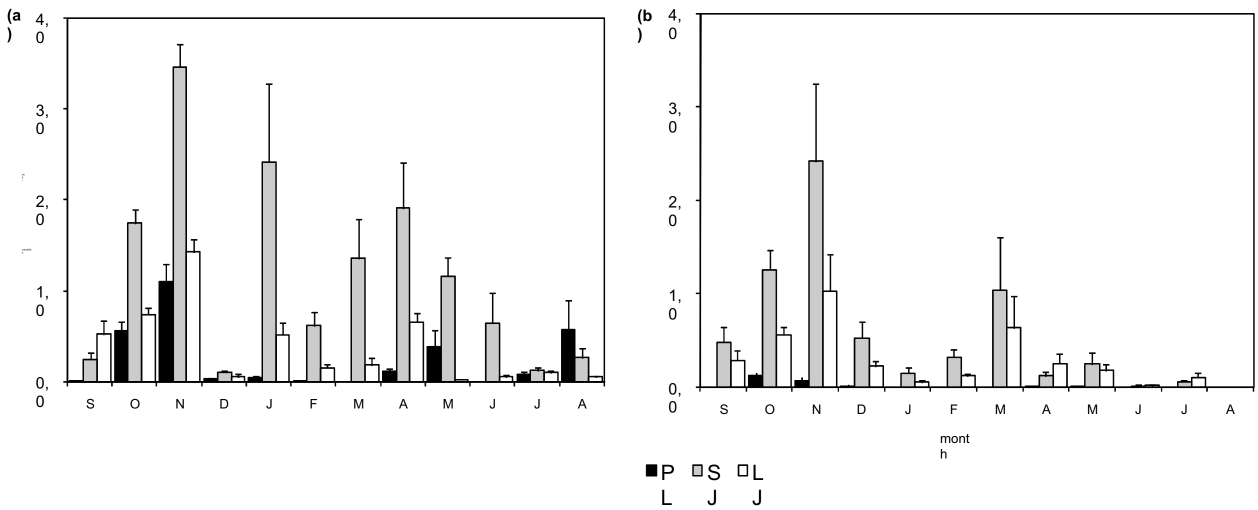

Figure 2. Abundance monthly average (n° of shrimps.m^{-2}) of various size categories (PL: Postlarvae, SJ: small juveniles ; LJ : Large juveniles) of (a) F. indicus and (b) M. monoceros

Recruitment

The introduction of *F. indicus* postlarvae (Figure 3a.) in mangrove waters is done gradually but mainly at the beginning of the wet season (October-November), at the beginning of the dry season (April-May) and during the dry season (July-August). The emigration of *M. monoceros* large juveniles from mangrove zones are more intense at the beginning of the wet season (October-November); continue at the end of the wet and hot season (March to May) and are less intense during the dry season (July to August) (Figure 3b.).

The rains occurring fifteen days before the samplings are negatively linked (Figure 3a.) with the immigration of postlarvae (r= -0.62 for *F. indicus* and r= -0.34 for *M. monoceros*). Mangroves water salinity does not show any significant correlation with the movement of young shrimps. Among *M. monoceros*, the correlation between water temperature and emigration of large juveniles (r = 0.54) is significant (Figure 3b.).

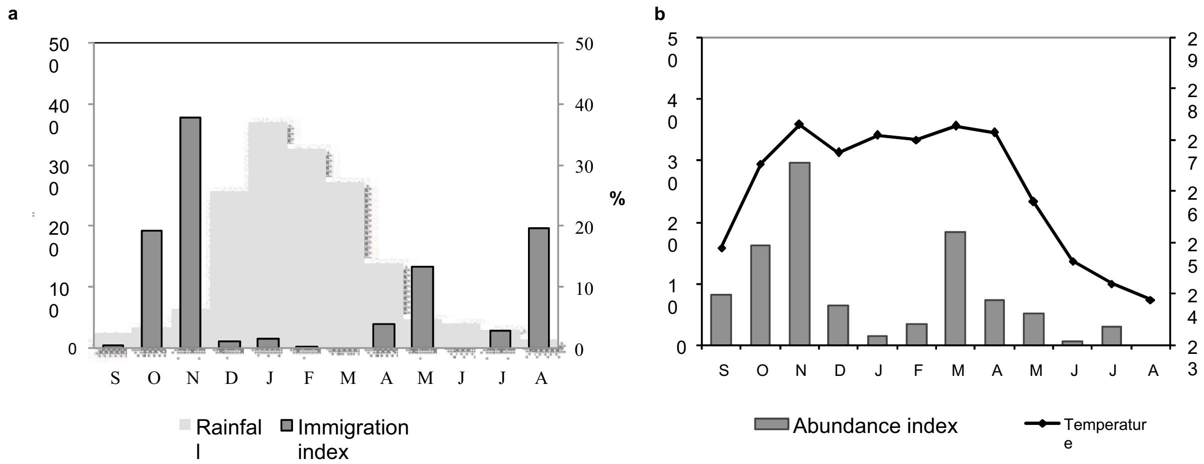

Figure. 3. Seasonal variations of a) Immigration index of F. indicus postlarvae and rains b) Abundance index of M. monoceros large juveniles and water temperature

Discussions

The constant abundance of small juveniles in the samplings confirms the role of nursery played by the Ambaro Bay. With the same methods and sampling sites, the number of shrimps captured in this survey is low as compared to the number obtained in previous works (Rasolofo, 1990). However, the estimated density values are comparable to those of other studies carried out on the same species (Rönnback *et al*, 2002; Macia, 2004). The marked low density values among *M. monoceros* are a result of often null postlarvae captures. Even though the sampling methods were not the same, the biannual common recruitment among penaeid shrimps (Ahmad-Adman et al., 2002) was found in the present study with the emergence of two main recruitment periods in mangrove zones. The immigrations of postlarvae at the beginning of the wet season for the two species, clearly show the reproduction peeks (egg laying period) defined in previous works by Le Reste (1978) and Rafalimanana (2003).

The inhibition of the coming of postlarvae during the wet season could result from the increase of flows in the rivers after heavy rains, by retaining postlarvae in marine waters. The study showed a significant correlation between climatic factors (temperature and rains) and the recruitment of young shrimps. Moreover, the climatic changes such as the increase in temperature and the increase of rainwater can affect the natural stock of shrimp resources in coastal areas. Moreover the inherent development of shrimp aquaculture in Malagasy mangroves runs the risk of compromising the habitats (nursery zones) of young shrimps and consequently of shrimp fisheries.

Conclusion
The evaluation of the abundance of small juveniles indicates the importance of mangroves in the Ambaro Bay as a prospective nursery zone. In spite of the reduction of the campaign to only one annual sampling cycle, the analysis of abundance variations identified two main abundance and recruitment periods with a season dynamics almost similar for the two species.

Perspectives for research and development
In future research, it will be important to have a better knowledge of ecological structures and functions of nursery zones, by focusing research on a characterization of mangroves, considering possible changes of environmental factors as well as the negative effects of the development of shrimps aquaculture on coastal ecosystems.

For mangroves, it is vital to practice an integrated approach for a sound exploitation of resources. Development activities should thus make provision for the protection of specific biological stages (larvae, postlarvae) and the critical habitats for their development. Exploitation standards should be put in place and followed by an actual enforcement for the sustainability of shrimp and other natural resources and their exploitation. Finally, a participatory consultation is advisable following the example of the ZAC projects (Concerted Development Zones) which have had impacts at the Ambaro Bay.

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